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Key words	End-of-Life Vehicle (ELV), Automobile Shredder Residue (ASR), Lead, Population balance model, Substance Flow Analysis

Abstract

Since End-of-life vehicles (ELVs) contain toxic substances, they have to be treated properly. The purpose of this study was to obtain useful information for ELVs management from the viewpoint of toxicity. We focused on lead as a representative toxic substance contained in vehicles and investigated the dynamic substance flow of lead contained in ELVs and its content in automobile shredder residue (ASR). A population balance model was used to estimate the number of ELVs generated between FY (fiscal year) 1990–2020, employing a Weibull distribution for the lifespan distribution. 16 lead-containing components of the vehicle were considered. It was estimated that the annual number of ELVs generated would be 2.9 million as of FY2020. The results implied it is hard to remove Pb completely. This is because 5,000–11,000 t-Pb will still remain in vehicles in use in FY2020 even though most components in new model vehicles could be replaced by lead-free alternatives. As of FY2010, the substance flow showed that Pb contained in ELVs amounted to 4,600–5,700 t-Pb. Of this, 13.2–14.0% was contained in ASR. The Pb content in ASR could be dramatically decreased by FY2020, but it will continue to contain 240–420 mg-Pb/kg if the treatment system is not improved.

Introduction

The automotive industry is one of the biggest industries in the world, as vehicles are indispensable for modern life. Unlike other used products such as home appliances and small electronic equipment, ELVs (end-of-life vehicles) can easily be monitored and collected because every owner can be identified by the vehicle registration system. Common metals (ferrous and non-ferrous) account for a high proportion of the total weight of a vehicle; ferrous and non-ferrous metals account for approximately 70–80% and 5–10% of a passenger vehicle, respectively [1]. The remaining weight consists of other materials such as plastics and rubbers. Some components contain toxic substances such as lead, mercury, and cadmium, and therefore, vehicles should be collected and treated properly at the end of their useful lifespan.

In Japan, MITI (the Ministry of International Trade and Industry, Japan) issued the “Automobile recycling initiative” in 1997 [2]. Then, JAMA (Japan Automobile Manufacturers Association, Inc.) established an action plan and revised it in 2002 considering EU Directive (2000/53/EC) [3]. One of their targets was to reduce the Pb content of components of passenger vehicles (except for the lead-acid battery) by more than 90% by 2006, compared to the total content in 1996 of 1,850 g-Pb per vehicle. This target was continued after January 2006 and this progress was considered in our analysis.

Estimating the number of disposed ELVs not only in the past and present but also in the future is necessary for ELV management. A population balance model (PBM) is a dynamic estimation model that can be described basing on the mass balance between input, stock, and output of materials or products that have a lifespan. For instance, Kim et al. [4] estimated the amount of WEEE generated in the period 2000–2020 in South Korea and Polák et al. [5] estimated the number of mobile phones generated in 1990–2020 in the Czech Republic. Estimation of the flow of toxic or valuable substances contained in a product is also possible by employing a material flow analysis of the product using PBM. Tasaki et al. [6] conducted a substance flow analysis (SFA) of brominated flame retardants (BFRs), Sb, and PBDDs/DFs in components of TV sets after predicting the material flow of TV sets in the period 1995–2020. Daigo et al. [7] estimated the amount of copper and copper alloy generated from in-use stock including vehicles. They also estimated the amount of Cr and Ni in stainless steel [8].

With regard to the SFA of lead, Tukker et al. [9] conducted an SFA to analyze trends in uses and emissions of lead in the EU from 2000 to 2030. Elshkaki et al. [10] developed dynamic SFA, which combines physical and socio-economic elements to estimate lead demand and supply in different applications. They also used SFA to demonstrate that non-intentional flows of lead originating from mixed primary resource applications such as the production of zinc are larger than those originating from the waste streams of intentional applications of lead [11]. Fuse et al. [12] showed the impact of this by shifting to lead-free solders in Japan using dynamic material flow analysis. Although there have been some studies focused on the SFA of lead or on the elemental analysis of lead content in ASR, which will be mentioned later, few studies have applied dynamic SFA to lead contained in ELVs.

The purpose of this study was to obtain useful information for ELV management in Japan from the viewpoint of toxicity. We focused on lead as a representative toxic substance contained in vehicles and investigated the dynamic substance flow of lead contained in ELVs and its content in ASR after estimating the numbers of ELVs generated in the past, present, and future.

Materials and methods

Generation of ELVs

The dynamic generation of ELVs between FY1990 and FY2020 was estimated using PBM. Here, passenger vehicles and freight vehicles were considered, while light motor vehicles (below 660 cc displacement) were excluded owing to a lack of data. It was considered that passenger vehicles and freight vehicles were sufficient to elucidate the disposal trend of ELVs, as the number of light motor vehicles in use in Japan accounted only for 36.8% of the total number of vehicles in use at the end of FY2010 [13] [14].

PBM considers the lifespan of a vehicle and was used to estimate the number of ELVs generated. The lifespan in this study was defined as the period from the fiscal year in which the vehicle was first registered in Japan to the fiscal year when its registration was cancelled. Owing to a shortage of data, all vehicles whose registration had been cancelled were regarded as ELVs, although some vehicles were exported after the registration had been cancelled. Statistical data did not differentiate exported used vehicles from new ones until FY2001. In the estimation of the flow of Pb, export was considered only between FY2001 and FY2011.

The estimation process is depicted in Fig. 1. To estimate the number of ELVs generated, the annual number of vehicles whose first registration year, as reported by AIRIA (Automobile Inspection & Registration Information Association) and JADA (Japan Automobile Dealers Association) [15], was between FY1973 and FY2010 was used as past data and between FY2011 and FY2020 was used as prospective future data. The annual total number of ELVs generated in FY Y could be calculated by summing up the number of ELVs generated by first registration year, as shown in Eq. 1. The number of ELVs generated in FY Y, which were first registered in year y, was calculated by subtracting the number of vehicles in use, as shown in Eq. 2.

$$N_{ELV}^{Y} = \sum_{y} N_{ELV}^{Y}(y) \quad (1)$$

$$N_{ELV}^{Y}(y) = N_{Use}^{Y-1}(y) - N_{Use}^{Y}(y) \quad (2)$$

Y : Counted fiscal year

N^{Y}_{ELV} : The annual total number of ELVs generated in FY *Y*

$N^{Y}_{ELV}(\mathrm{y})$: The number of ELVs in FY *Y* that were first registered in year *y* and disposed of

$N^{Y}_{Use}(y)$: The number of vehicles in use in FY *Y* that were first registered in year *y*

To estimate the number of vehicles in use, $N^{Y}_{Use}(y)$, a lifespan distribution with respect to the first registration year had to be determined. A Weibull distribution, which has been frequently used in previous studies [4-8], was employed for the lifespan distribution of a vehicle. Considering that the remaining rate obtained from actual statistical data showed a sharp decrease soon after registration, a combination of two Weibull distributions with the same average lifespan were assumed: the first distribution describes the user group that tends to dispose of their vehicles relatively soon after registration and the other describes the user group without such preferences. The remaining rate function of the vehicle for the first registration year y can be described by Eq. 3. It was assumed that the lifespans of different types of vehicles were not different but varied by their first registration years. Linear approximations were assumed for the shape parameter (p_y, q_y), the scale parameter, and the proportion r_y from FY1990 to FY2020 of those parameters between FY1979 to FY1994 were obtained using the maximum likelihood method, as explained below.

$$F(y,t) = exp\left\{-\left(\frac{t+0.5}{\eta}\right)^{\mathrm{p_y}}\right\} \times r_y + exp\left\{-\left(\frac{t+0.5}{\eta}\right)^{\mathrm{q_y}}\right\} \times (1 - r_y) \tag{3}$$

$F(y,t)$: Remaining rate

y : First registration year

t : Vehicle age

p_y, q_y : Shape parameter

η : Scale parameter

r_y : Proportion of two distributions

The discard rate $D(y|t)$ for a vehicle first registered in the year *y* and disposed of at an age greater than *t* and less than *t+1* can be described using the remaining rate function $F(y,t)$, as shown in Eq. 4, and was expressed as $D_{t,t+1}$. Here, the probabilities $D(y|t = 0, 1, 2, \cdots)$ are independent of one another. In addition, the number of ELVs first registered in year *y* and disposed of at the age of *t* was $N_{ELV}(y,t)$. Therefore, the likelihood of this can be described by Eq. 5 and its log likelihood function is given by Eq. 6. Then, each parameter in $F(y,t)$ can be determined when $\mathrm{L(y)}$ is maximised.

$$D(y|t) = \int_{t}^{t+1} F(y,t)\ dt = D_{t,t+1} \tag{4}$$

$$l(y) \propto \left(D_{0,1}\right)^{N_{ELV}(y,0)} \times \left(D_{1,2}\right)^{N_{ELV}(y,1)} \cdots \times \left(D_{n,\infty}\right)^{N_{ELV}(y,n)} \quad (5)$$

$$L(y) \propto \sum_{t} \{E(y,t) \times ln\, D_{t,t+1}\} \quad (6)$$

$D(y|t)$: Discard rate of a vehicle first registered in year y and disposed of at an age greater than *t* and less than *t+1* ($= D_{t,t+1}$)

$l(y)$: Likelihood function

$L(y)$: Log likelihood function

Average weight of a vehicle

The average weight of a vehicle by its first registration year, $Wa_{Use}(y)$, was estimated to consider that the weight has tended to increase over time. AIRIA reports the number of vehicles by both first registration year and vehicle weight [16, 17]. Using these data, the mass balance equation of the vehicles in use for each FY can be described by Eq. 7. Then, the average weight of a vehicle first registered in year *y* between 1991 and 2009, $Wa_{Use}(y)$, was calculated. A linear approximation was applied to estimate the average weight for other years, including those in the future.

$$Wt_{Use}^{Y} = \sum_{y} \{N_{Use}^{Y}(y) \times Wa_{Use}(y)\} = \sum_{u} \{N_{Use}^{Y}(u) \times Wa_{Use}(u)\} \quad (7)$$

Wt_{Use}^{Y} : Total weight of vehicles in use in FY *Y*

$N_{Use}^{Y}(u)$: The number of vehicles in use in FY *Y* categorized as *u* on a weight basis

$Wa_{Use}(y)$: Average weight of a vehicle first registered in year *y*

$Wa_{Use}(u)$: Average weight of a vehicle categorized as *u* on a weight basis.

Pb content in ELV and ASR

The 16 components of the new model vehicle that contained Pb as of 1996 were reported by JAMA. Lead-acid batteries were not included in these components because they are dealt with under another recycling scheme. JAMA and car producers have published the progress of reduction for each component based on their action plans. According to the reported information, progress was divided into three periods: no reduction, under reduction, and reduction complete (lead free). A linear reduction in Pb content was assumed during the reduction period. The assumed Pb contents in each component for every sales release year are shown in Table 1. Most components in new model vehicles sold after 2006 achieve a “lead-free” status, except for printed circuit board, other engine components, and other car components.

The Pb content per vehicle for every first registration year was estimated using the Pb contents of each component in Table 1. The Pb contents of vehicles that will be sold between 2011 and 2020 were assumed to decay exponentially. Here, not all vehicles sold as of year *y* are new models. It is not clear whether components in vehicles sold before year *y* are replaced with newer ones containing less Pb. Therefore, two cases were assumed in the analysis. The first case is referred to as the “minimum case,” in which it is assumed that the Pb content in a vehicle registered in year *y* and started to be sold before *y* equals the Pb content of the newest model in year *y*. The other case is the “maximum case,” in which it is assumed that the components are not replaced with newer model ones until full model of the vehicles is started selling. It is thought that the actual Pb content per vehicle will be in the range of these two cases.

After usage, depending on the ELV treatment system, components containing Pb enter three streams in stages. First, some components of the ELV are dismantled and collected in the dismantling process. Then, the ELV with the remaining components is shredded and some fraction of this is recovered as resources. Finally, the remaining fractions are disposed of as ASR and treated in ASR recycling facilities. In this way, Pb contained in the vehicle components is partitioned into each stream. Table 2 shows the partition ratio on a weight basis.

The amounts of Pb contained in vehicles in use and ELVs for every first registration year were estimated by multiplying the number or weight of vehicles by the Pb content per vehicle. Additionally, partition ratios were multiplied to estimate the Pb content in collected components, recovered resources, and ASR. The total weight of ASR generated in FY *Y* was estimated using Eq. 8, which JAMA obtained by shredding experiment [19].

$$Wt_{ASR}^{Y} = 0.1819 \times Wt_{ELV}^{Y} - 11.078 \tag{8}$$

Wt_{ASR}^{Y} : Total weight of ASR generated in FY *Y* [kg]

Wt_{ELV}^{Y} : Total weight of ELVs generated in FY *Y* [kg]

Results and discussion

Generation of ELVs

The estimated results with statistical data are shown in Fig. 2. The number of ELVs generated annually decreased after FY2003 while it had increased up until then. As of FY2010, 3.8 million ELVs were estimated to be generated annually, and 2.9 million were predicted to be generated in FY2020. The calculation error in each estimate against the actual statistical data between FY1990 to FY2010 seemed large, ranging between -21.3 and 35.7%. However, the trends of ELV generation were considered to be well described because the calculation error in the estimated total numbers of ELVs against the total number of actual statistical data in these periods was 0.69%. It should note that this estimated generation of ELVs includes exported ELVs.

Dynamic SFA of Pb in vehicles

The estimates of the amount of Pb potentially contained in the vehicles are shown in Fig. 3. Reductions in the Pb content of vehicles and the decrease in the number of vehicles in use resulted in a reduction in the net amount of Pb. In total, a 54–69% reduction in the Pb content was achieved between FY1995 and FY2010, while a 72-81% reduction is to be expected between FY2010 and FY2020. This result shows that it is hard to remove Pb completely, and 5,000–11,000 t-Pb will remain in vehicles in use in FY2020, even though most components will have been replaced with lead-free alternatives.

After disposal as of an ELV, most ELVs were treated in Japan, whereas some wereexported as used vehicles. Fig. 4 shows the partitioning of Pb contained in ELVs in FY2001–2011. The reduction of Pb contained in ASR seemed slower than in the other streams because components containing Pb, such as printed circuit board, tended to be partitioned to ASR. Fig. 5 shows the substance flow of Pb as of FY2010. Pb contained in vehicles in use and in ELVs accounted for 26,000–39,000 t-Pb (590–890 g-Pb per vehicle) and 4,600–5,700 t-Pb (1,200–1,500 g-Pb per vehicle), respectively. Thus, compared to a vehicle in use, an ELV seems to contain larger amounts of Pb. This is because ELVs are older and contain more Pb, whereas vehicles in use are newer and contain less Pb.

The results indicated that 19.5–21.1% of Pb contained in ELVs ends up in foreign countries as used vehicles. This outflow may cause pollution if they are not properly treated after usage in the countries to which they are exported. With respect to the domestic treatment stream, most Pb is partitioned into collected components in the dismantling process, with 13.2–14.0% of Pb in ELVs estimated to be contained in ASR. As comparison to a previous study, Fuse et al. [20] estimated that 38,000 t-Pb were contained in ELVs generated as of 2005, but this included lead-acid batteries. If the Pb content in a lead-acid battery and in an ELV excluding the battery are assumed to be 7.9 kg-Pb [21] and 1.85 kg-Pb, respectively (using reported the values reported by JAMA), the Pb content in ELVs excluding lead-acid batteries is estimated to be 7,200 t-Pb. Our estimate, which was in the range 7,200–7,700 t-Pb as of FY2005, was quite similar to this value.

Pb content in ASR

The estimated Pb content in ASR displayed in Fig. 6 (a) shows that even if there is no reduction, the Pb concentration may decrease. This is because the weight of the vehicle tends to get heavier compared with the past. As a result, the relative Pb content per vehicle decreases.

Fig. 6 (b) shows the Pb content in ASR compared to the case with no reductions. This indicates that it will take some time for the activities of car producers to reduce Pb content in vehicle components to have an effect, although both the minimum and maximum cases showed dramatic decreases in Pb content from FY1996 to FY2020. Approximately 5 years are needed to begin to reduce the Pb content in ASR. As of FY2010, a 14–23% Pb reduction in ASR was estimated to have been achieved and this is expected to increase to 58–76% by FY2020. However, ASR will continue to contain 240–420 mg-Pb/kg in the future if the treatment system is not improved.

Pb content in ASR has been reported in some previous studies, as shown in Table 3. Pb content ranged from several hundred to several thousand ppm. However, the average value was generally under 3,000 ppm regardless of the region or time. The average value reported in Japan ranged between 920 and 2,700 ppm and our estimated values in Fig. 6 (a) fall into this range. ASR consists of various materials with different particle diameters. The fine ASR fraction generally contains the highest heavy metal concentrations [22] [23]. One of the difficulties of measuring the physical properties of ASR is how to obtain representative samples, as the composition of ASR depends on its pre-treatment such as dismantling and shredding.

Uncertainties

There are uncertainties in the estimation of ELVs generated, such as the future data reported by AIRIA being used as the number of vehicles first registered after FY2011. The number of sales will be affected by factors such as the market, lifestyle, and personal preferences. In addition, the assumed lifespan distribution was based on conventional vehicles. If the proportion of next-generation vehicles such as hybrid vehicles increases in the future, their lifespan may show different distributions.

We also have to clarify the substance flow of Pb after partitioning collected components, and recovering resources and ASR for the management of toxic substances. The ELV treatment stream was assumed to remain the same in the future. If collected components in the dismantling process and recovered resources in the shredding process are increased, the material flow of ELVs and substance flow of Pb contained in ELVs will change. For example, if more printed circuit board, which still contained Pb as of FY2010, could be collected separately in the dismantling or shredding process, the Pb content in ASR would decrease. Furthermore, we may be able to collect valuable substances contained in the printed circuit board.

This study focused only on the toxic substance, Pb, contained in a vehicle. Fuse et al. [40] estimated that 32,000 ton of Pb flowed through the international market as imported or exported used passenger vehicles in 2005, while the values were 3.4 million ton for ferrous materials, 310,000 ton for aluminium, and 75,000 ton for copper. They also estimated that 22,000 ton of manganese, 4,300 ton of nickel, 34,000 ton of chromium, and 1200 ton of molybdenum derived from engines exited Japan as used vehicles, used parts, and secondary materials between 1988 and 2005 [20]. Therefore, ELVs include both valuable and toxic substances, and with innovations in technology, vehicles contain increasing amounts of valuable substances. Thus, ELV management from such a viewpoint is also important, and we will study this in the future.

Conclusion

ELVs must be treated properly as they contain toxic substances. The purpose of this study was to obtain useful information for ELV management from the viewpoint of toxicity. We focused on lead as a representative toxic substance contained in a vehicle and investigated the dynamic substance flow of lead contained in ELVs and its content in ASR after estimating the number of ELVs generated in the past, present, and future.

The annual number of ELVs generated was estimated to be 3.8 million as of FY2010 in Japan. The number decreased from FY2003 and was expected to be 2.9 million by FY2020. The effect of the reduction of Pb content in a vehicle and the lower number of vehicles in use could reduce the net amount of Pb contained in ELVs. However, the result also demonstrated that it is difficult to remove Pb completely. This is because 5,000–11,000 t-Pb will still remain in vehicles in use in FY2020 even though most components in new model vehicles could be replaced with lead-free alternatives. The substance flow as of FY2010 showed that Pb contained in ELVs accounted for 4,600–5,700 t-Pb. Of this, 13.2–14.0% or 650–749 t-Pb was estimated to be contained in ASR. Pb content in ASR could be dramatically decreased from FY1996 to FY2020, but ASR will continue to contain 240–420 mg-Pb/kg in the future if the treatment system is not improved.

This study focused only on Pb contained in a vehicle as a toxic substance. ELVs also contain some valuable substances, and in our next study, we will consider an ELV management system considering the amounts of both toxic and valuable substances based on elemental analysis and substance flow analysis.

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Figure captions

Fig. 1 Image of estimation process

Fig. 2 Estimated results and statistical data of ELV generation between FY1990 and FY2020. Exported vehicles were included.

Fig. 3 Estimated amount of Pb in vehicles in Japan in FY1990–2020: (a) Minimum case, (b) Maximum case. Pb derived from lead-acid battery was excluded.

Fig. 4 Estimated partitioning of Pb for ELVs generated in FY2001–2011 (Minimum case). Pb derived from lead-acid batteries was excluded

Fig. 5 Substance flow of Pb for ELVs generated as of FY2010. Pb derived from lead-acid battery was excluded.

Fig. 6 (a) Estimated Pb content in ASR and (b) reduction of Pb content, compared to “No reduction case” between FY1990 and FY2020

Table 1 Pb contents in each component for every sales release year of a new model vehicle. Pb contents for each component as of 1996 were reported by JAMA.

Table 2 Partition ratios of Pb for each component

Table 3 Pb content in ASR reported in previous studies

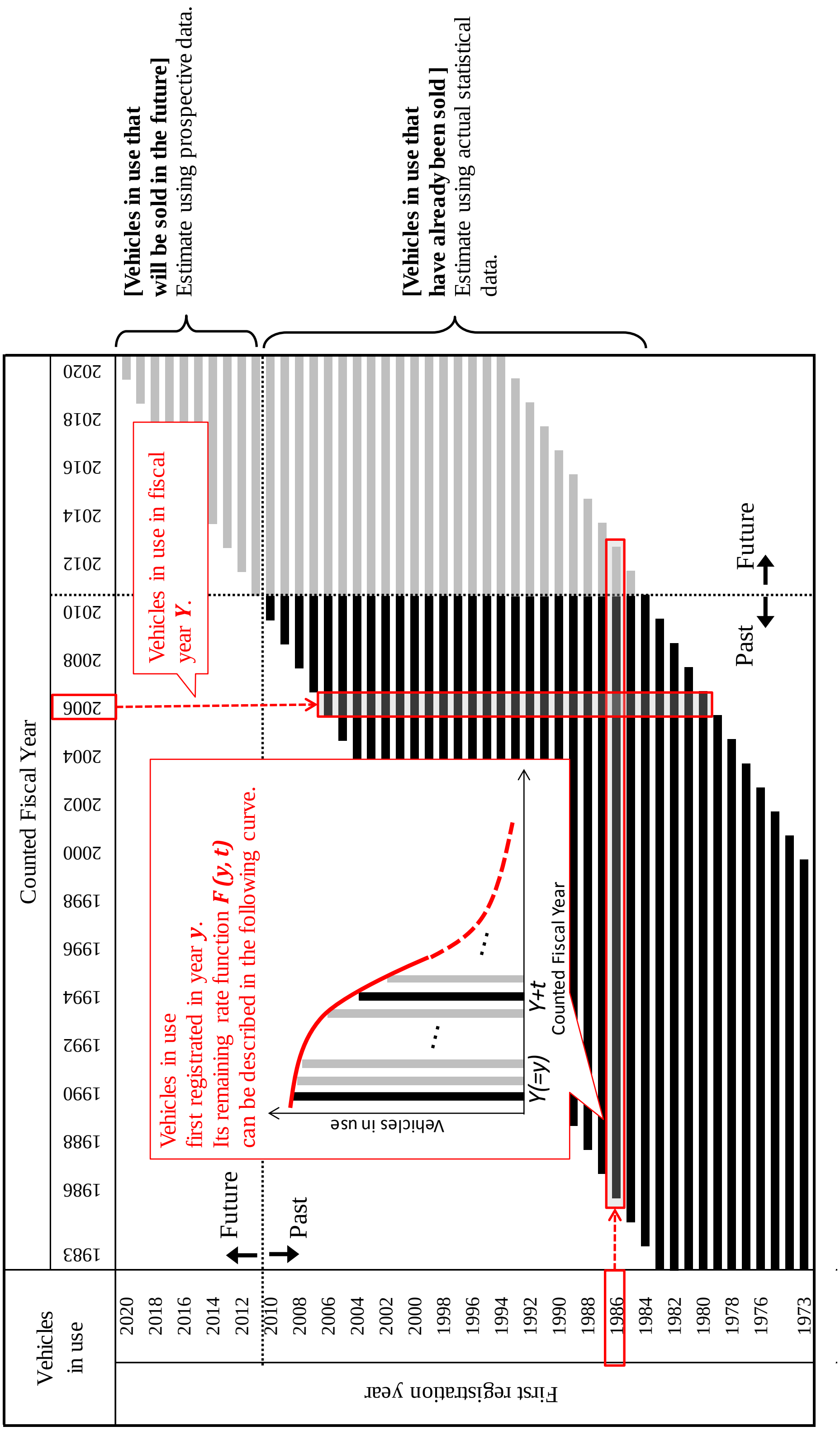


Fig. 1 Image of estimation process

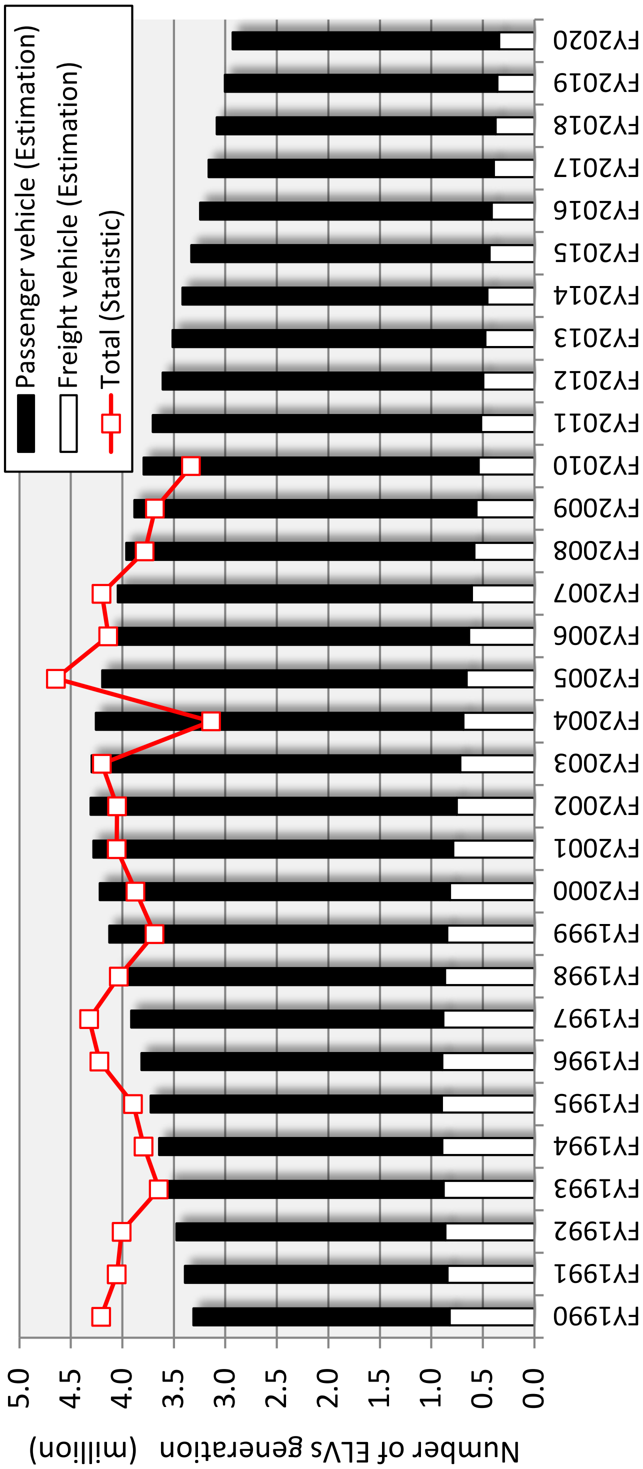
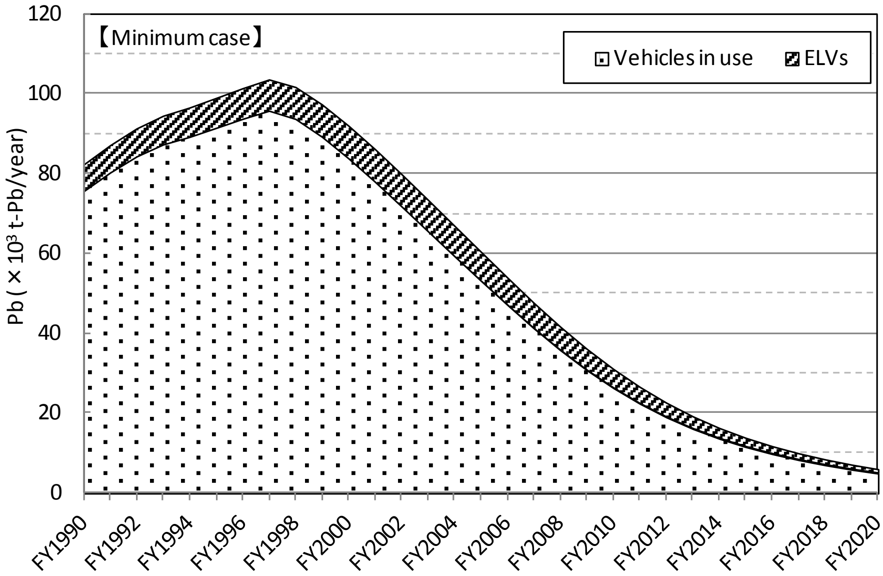
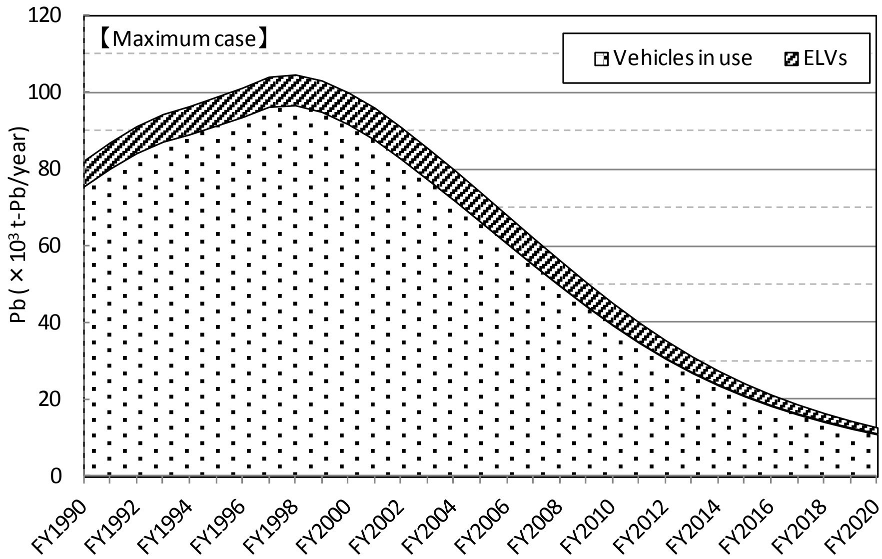


Fig. 2 Estimated results and statistical data of ELV generation between FY1990 and FY2020. Exported vehicles were included.



(a)



(b)

Fig. 3 Estimated amount of Pb in vehicles in Japan in FY1990–2020: (a) Minimum case, (b) Maximum case. Pb derived from lead-acid battery was excluded.

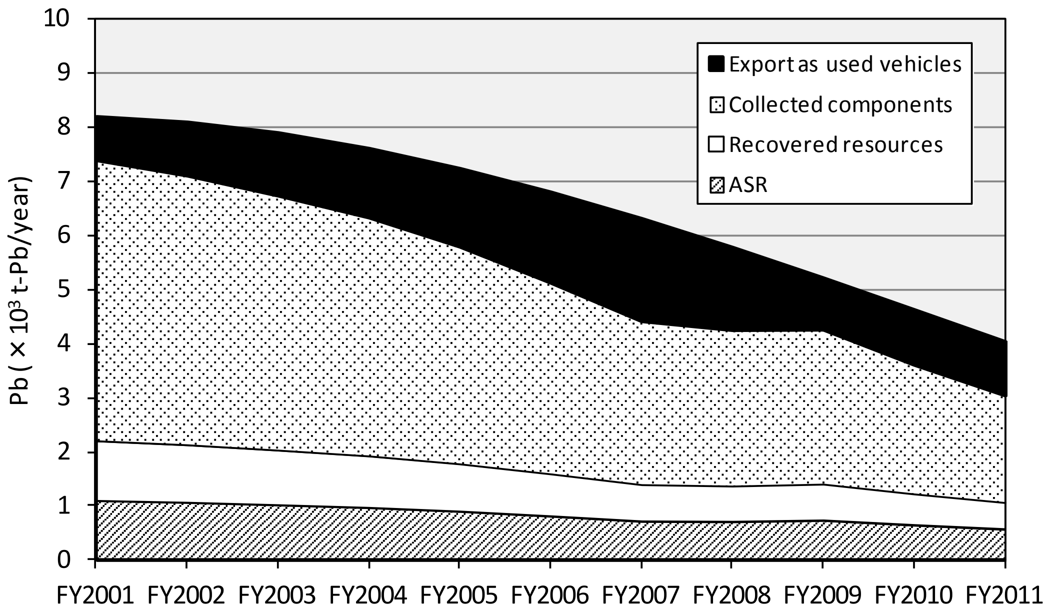


Fig. 4 Estimated partitioning of Pb for ELVs generated in FY2001–2011 (Minimum case). Pb derived from lead-acid batteries was excluded.

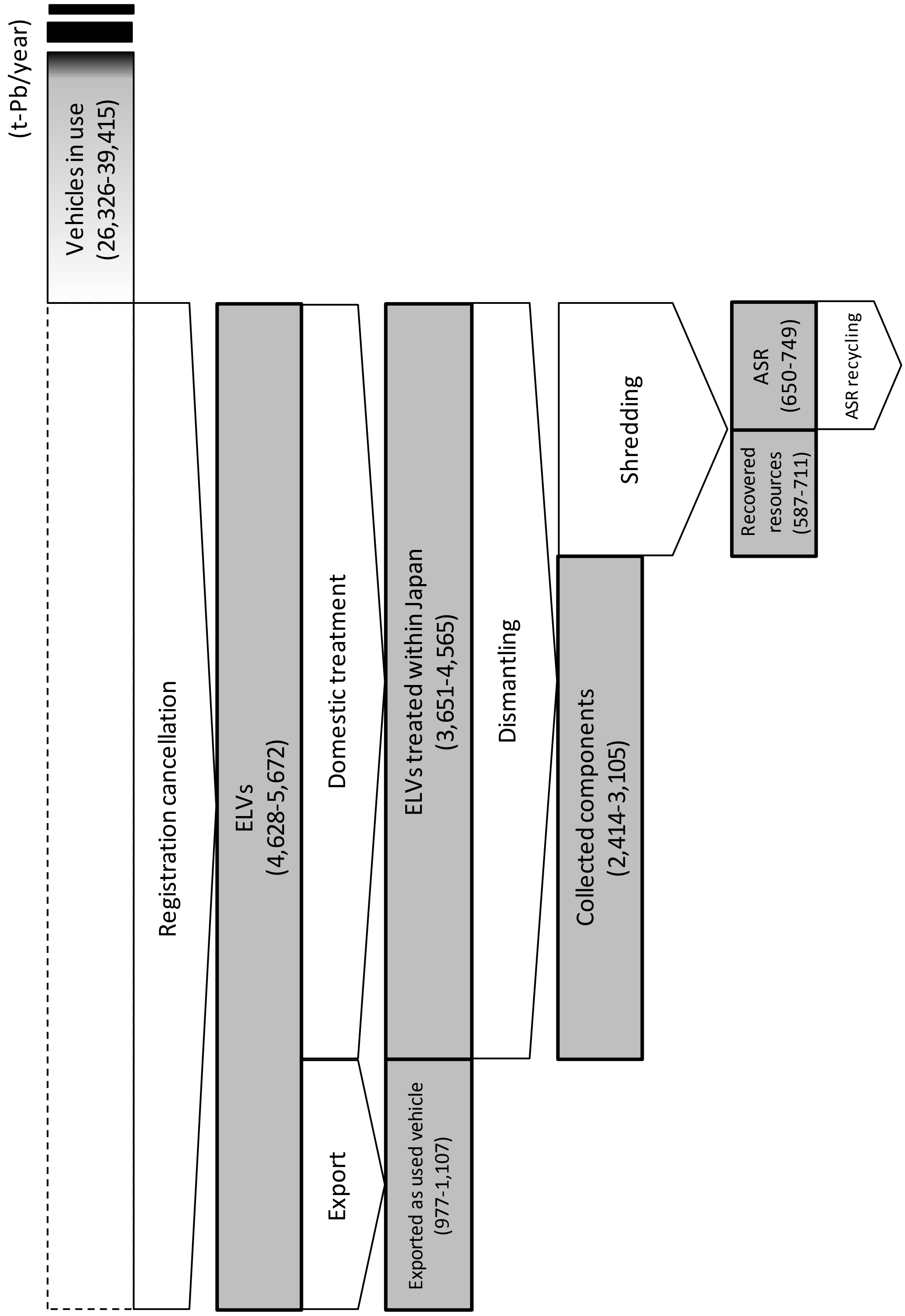
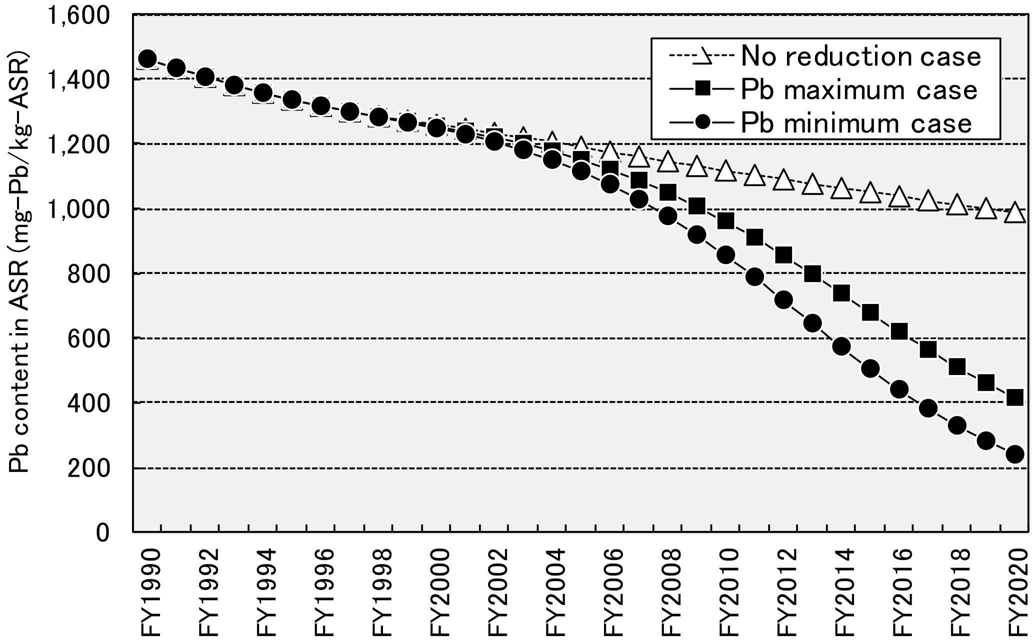
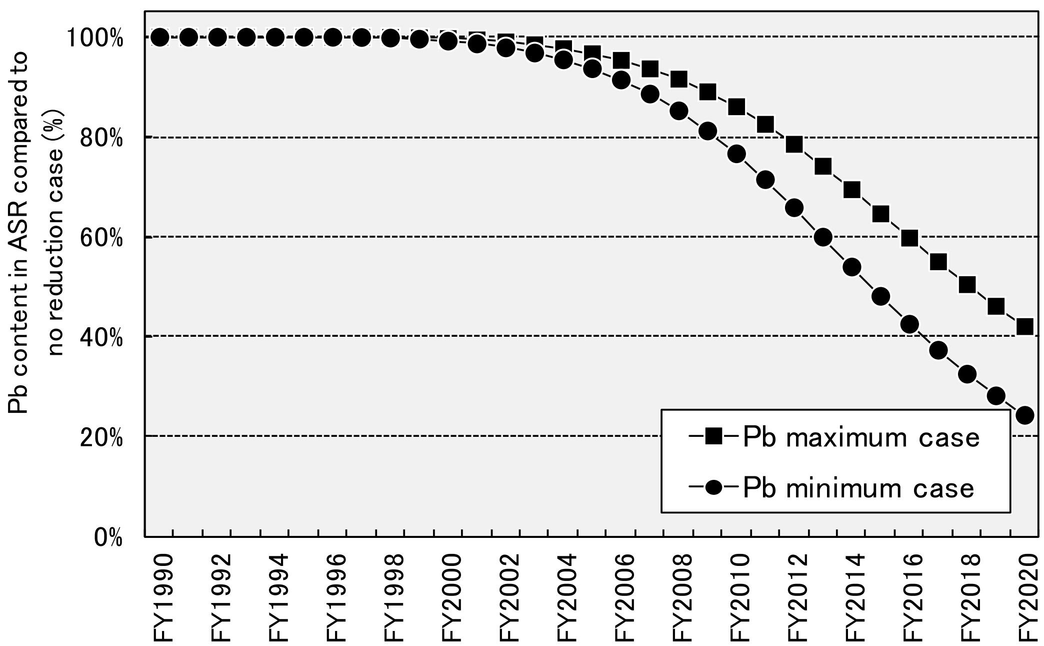


Fig. 5 Substance flow of Pb for ELVs generated as of FY2010. Pb derived from lead-acid battery was excluded.



(a)



(b)

Fig. 6 (a) Estimated Pb content in ASR and (b) reduction of Pb content, compared to "No reduction case" between FY1990 and FY2020

Table 1 Pb contents in each component for every sales release year of a new model vehicle. Pb contents for each component as of 1996 were reported by JAMA.

Components	Sales release year of a new model vehicle														
	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Copper radiator	580	290	0	0	0	0	0	0	0	0	0	0	0	0	0
Battery cable terminal	290	218	145	73	0	0	0	0	0	0	0	0	0	0	0
Wheel balancer	240	240	213	187	160	133	107	80	53	27	0	0	0	0	0
Fuel tank	200	180	160	140	120	100	80	60	40	20	0	0	0	0	0
Heat core	110	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Harness	90	77	64	51	39	26	13	0	0	0	0	0	0	0	0
Electrodeposition	50	50	50	44	38	31	25	19	13	6	0	0	0	0	0
Printed circuit board	50	50	50	50	50	50	50	50	50	47	45	42	37	45	35
Under coating	20	15	10	5	0	0	0	0	0	0	0	0	0	0	0
Fuel hose	20	16	12	8	4	0	0	0	0	0	0	0	0	0	0
Seatbelt G sensor	20	15	10	5	0	0	0	0	0	0	0	0	0	0	0
Glass-ceramic	15	13	10	8	5	3	0	0	0	0	0	0	0	0	0
Side protection mold	10	8	5	3	0	0	0	0	0	0	0	0	0	0	0
Power steering hose	5	5	4	3	1	0	0	0	0	0	0	0	0	0	0
Other engine component	100	100	100	100	100	100	100	100	100	81	61	42	37	45	35
Other car component	50	50	50	50	50	50	45	40	34	29	24	19	16	20	16
Total	1,850	1,327	883	727	567	493	420	349	290	210	130	103	91	111	86

: No reduction : Under reduction (Unit: g-Pb/vehicle)

Table 2 Partition ratios of Pb for each component

Components	Partition ratio of Pb (Assumption)					
	Dismantling		Shredding		ASR treatment	
	Components collected		Recovered resources		ASR	
Copper radiator	99.6%	(A)	0.4%	(B)	0.0%	(E)
Battery cable terminal	69.6%	(A)	30.4%	(B)	0.0%	(E)
Wheel balancer	49.3%	(A)	0.0%	(E)	50.7%	(C)
Fuel tank	78.2%	(A)	21.8%	(B)	0.0%	(E)
Heat core	69.9%	(A)	30.1%	(B)	0.0%	(E)
Harness	77.6%	(A)	11.2%	(D)	11.2%	(D)
Electrodeposition	0.0%	(E)	50.0%	(D)	50.0%	(D)
Printed circuit board	0.0%	(E)	50.0%	(D)	50.0%	(D)
Under coating	0.0%	(E)	50.0%	(D)	50.0%	(D)
Fuel hose	21.8%	(A)	0.0%	(E)	78.2%	(C)
Seatbelt G sensor	0.0%	(E)	50.0%	(D)	50.0%	(D)
Glass-ceramic	13.8%	(A)	0.0%	(E)	86.2%	(C)
Side protection mold	0.0%	(E)	0.0%	(E)	100.0%	(C)
Power steering hose	27.5%	(A)	0.0%	(E)	72.5%	(C)
Other engine component	96.0%	(A)	4.0%	(B)	0.0%	(E)
Other car component	0.0%	(E)	50.0%	(D)	50.0%	(D)

A: Data from previous study [18]

B: Assuming that all remaining component is recovered after component collection in dismantling process

C: Assuming that all remaining component is disposed of after component collection in dismantling process

D: Assuming a 50:50 ratio

E: Assuming zero

Table 3 Pb content in ASR reported in previous studies

Authors	NoS	Pb content [mg/kg]		Country	Sampling Year	Remarks	Ref.
		Min-Max	Average				
Granata et al. (2011)	1	1,030–5,100	2,300	Italy	-	1 sample with 4 particle diameters	[24]
Santini et al. (2011)	3	442–600	510	Italy	-	Car fluff (light ASR)	[25]
Mancini et al. (2010)	3	2,088–2,322	2,205	Italy	2006		[26]
Morselli et al. (2010)	1	2,000–5,000	4,000	Italy	-	1 sample with 4 particle diameters	[23]
Kameda et al. (2009)	1	-	1,400	Japan	-		[27]
Gonzalez-Fernandez et al. (2009)	4	4,600–11,600	7,508	Spain	2005-2006	1 sample with 6 particle diameters	[28]
JESC (2009)	2	1,400–2,200	1,800	Japan	2009		[29]
Osada et al. (2008)	1	-	1700	Japan	-		[30]
Matsuto et al. (2007)	4*1	532–1,850	1,338	Japan	2003		[31]
Recycle One. Inc.(2007)	2	-	1,800	Japan	-		[18]
Zolezzi et al. (2004)	1	-	2,000	Italy	-		[32]
Gendebien et al. (2003)	1	-	2,710	EU	-		[33]
Ministry of the Environment, Japan (2003)	2	640–1,600	1,120	Japan	2003		[34]
JESC (2002)	4	490–1,200	920	Japan	2002		[35]
Börjeson et al. (2000)	7*1	4,050–12,200	6,983	Sweden	-	Plant, dismantling level, type of vehicle are different	[36]
Trouvé et al. (1998)	5	-	1,400	France	-		[37]
Saxena et al. (1995)	1	-	200	USA	-	Moisture content of 40.2%	[38]
Sakai et al. (1991)	3	1,300–4,800	2,700	Japan	-		[39]

NoS: Number of Samples, Ref.: Reference, *1: Only ASRs were counted